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Characteristics of wind forces acting on high-rise buildings with different corner shapes and side ratios

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SUMMARY:
Over the past few years, many skyscrapers have been constructed with diversified designs based on newly developed technologies. It is well known the corner modification of the building reduce the wind load in the past study. (For example, Kawai, 1998) To reduce wind resistant load, modification of building corner is adopted in design of high-rise buildings. It have a positive effect for surrounding wind environments which have also been improved. (For example, Xu et al., 2017) However, sufficient database for high-rise building with corner modification cannot be seen in building codes. Therefore, wind force experiments have been conducted to examine the wind force characteristics of high-rise buildings with different corner shapes such as prismatic, corner cut, corner chamfered and rounded. At the results, the wind force characteristics of high-rise buildings with various corner shapes and side ratios were investigated based on wind tunnel experiments. By changing the corner shapes, it was found that the wind force coefficients were lower than those of the prism. In addition, by changing the side ratio, the effect on the wind load when the corner shape was changed became smaller.

Keywords: Wind forces, Corner shape, Side ratio, Corner modification

1. INTRODUCTION

Over the past few years, many skyscrapers have been constructed with diversified designs based on newly developed technologies. It is well known the corner modification of the building reduce the wind load in the past study. (For example, Kawai, 1998) To reduce wind resistant load, modification of building corner is adopted in design of high-rise buildings. It have a positive effect for surrounding wind environments which have also been improved. (For example, Xu et al., 2017) However, sufficient database for high-rise building with corner modification cannot be seen in building codes. The object of this study is to investigate the wind force characteristics of high-rise buildings with different corner shapes such as prismatic, corner cut, corner chamfered and rounded based on wind tunnel experiments.

2. OUTLINE OF EXPERIMANT

2.1. Experimental condition

A wind force model was installed as shown in Fig. 1. For the rectangular models, the wide face was set as the windward face at the wind direction 0°. In addition, the structural axis and wind moment are defined as shown in Fig.1. The geometrical scale, the velocity scale and the time scale were 1/400, 1/4 and 1/100, respectively. The sampling frequency in the wind tunnel experiment was set at 600 Hz, the measurement time for each wind direction was 75 seconds (corresponding to 12 samples of 10 minutes in full-scale) and the wind speed at the top of the building in full-scale was assumed to be about 40 m/s. The wind direction was varied from 0° to 90° for the rectangular models (45° for square model).

2.2. Experiment model

Six types of the wind force models with different side ratios were tested as shown in Fig. 2. The depth D of the models was fixed to 75mm and the widths B were varied from 75mm to 225mm, giving side ratios B/D = 1, 1.2, 1.3, 1.5, 2 and 3. In this research, to investigate the effects of corner shape, 4 corner shapes (4 corners) were tested: (a) prism (without corner modification), (b) chamfered, (c) corner cut and (d) rounded, as shown in Fig. 3. In addition, for corner shapes (b), (c) and (d), 5 corner modification widths b were tested, as shown in Table 1. The corner modification rate b^* is defined as the width b divided by the depth D of the model. A total of 96 models for different side ratios B/D and corner modification rates b^* of 0.05, 0.08, 0.1, 0.15, and 0.2 were used.

2.3 Approach flow

For the approaching flow in the wind tunnel experiments, the profile of terrain roughness category IV (Power law index $\alpha = 0.27$) of the Recommendations for Loads on Building of the Architectural Institute of Japan (AIJ, 2015) was reproduced.

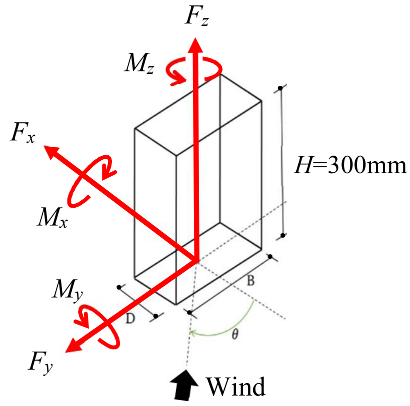
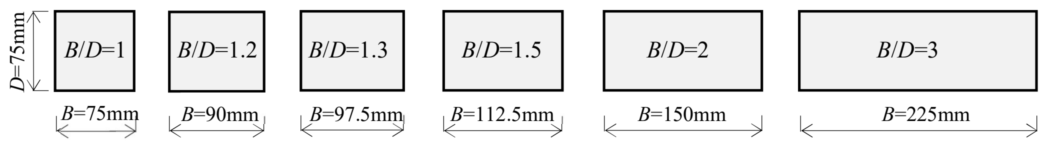
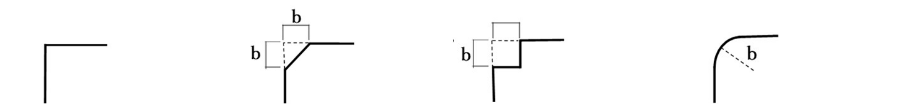


Figure 1. Wind force model and definitions of wind forces and moments



(a) B/D=1 (b) B/D=1.2 (c) B/D=1.3 (d) B/D=1.5 (e) B/D=2 (f) B/D=3

Figure 2. Side ratio (B/D) of models



(a) Prism (b) Corner chamfered (c) Corner cut (d) Rounded corner

Figure 3. Corner shapes of models

Table 1. Corner modification rate b^*

Corner size b [mm]	3.75	5.63	7.5	11.25	15
Corner modification rate $b^*=b/D$	0.05	0.075	0.1	0.15	0.2

3. ANALYTICAL METHOD

The measured wind forces and moments (shown in Fig.1) were normalized using the following equations.

$$C_{Fx(y)} = \frac{F_{x(y)}}{q_H B H} \qquad C_{Mx(y)} = \frac{M_{x(y)}}{q_H B H^2} \qquad C_T = \frac{M_T}{q_H B^2 H}$$

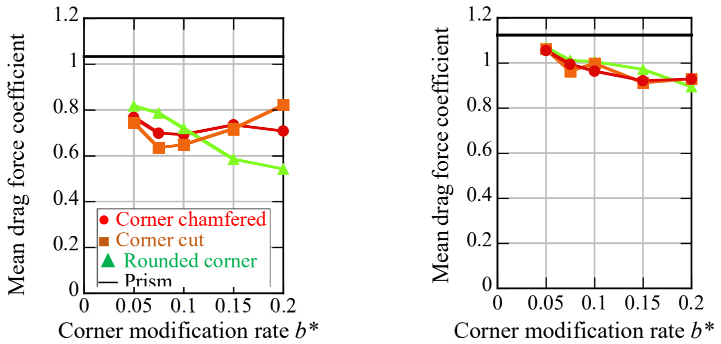
where $C_{Fx(y)}$: wind force coefficient in $x(y)$ direction, $F_{x(y)}$: wind force in $x(y)$ direction [N], $C_{Mx(y)}$: overturning moment coefficient around $x(y)$ axis, $M_{x(y)}$: overturning moment around $x(y)$ axis [Nm], C_T: torsional moment coefficient, M_T: torsional moment [Nm], q_H: velocity pressure [N/m^2], B: model width for wind direction 0° [m], and H: model height [m].
To investigate the effect of side ratio, the drag and lift force coefficients were calculated by the following equation.

$$C_{D(L)} = \frac{F_{D(L)}}{q_H A}$$

where $C_{D(L)}$: drag (lift) force coefficient, $F_{D(L)}$: drag (lift) force for wind direction normal to the face [N], A: projected area [m^2]

4. EXPERIMENT RESULTS

Fig. 4 shows the change in the mean wind force coefficient depending on the corner change rate. It can be seen that the mean drag coefficient is lower than that of the prism in all cases of modified corner shape, regardless of the side ratio. In Fig. 4(a), when the side ratio is 1, the cases of corner cut and corner chamfered show similar trends, and it can be seen that the mean drag coefficient is the smallest at a specific corner modification rate. For rounded corners, the mean drag coefficient decreases as the corner modification rate increases. Regarding the changes due to the corner shape, the mean wind force coefficient of the notched corner decreased the most when the corner modification rate was between 0.05 and 0.1.
At the side ratio of 3 in Fig. 4(b), there is not much difference due to the corner shape, and the mean wind force coefficient decreases as the corner modification rate increases.

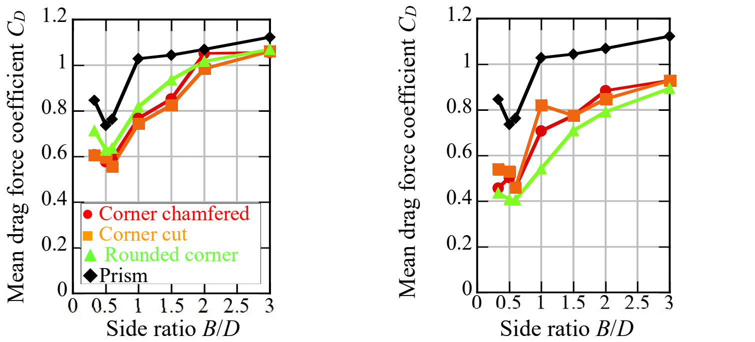


(a) Side ratio B/D=1 (b) Side ratio B/D=3

Figure 4. Changes of mean drag force coefficient with corner modification rate (Side ratio B/D=1)

Fig. 5 shows the variation of mean wind force coefficient with side ratio. Even in this case, it can be seen that the wind force is less than for the square shape in all cases. At a corner modification rate of 0.05, the mean wind force coefficient of the corner notch is the smallest for all side ratios. Even at the corner modification rate of 0.2 in Fig. 5(b), the wind force coefficient tends to increase as the side ratio increases. The reduction rate from the wind force coefficient of prism is larger than when the corner modification rate is small. Regarding the influence of the corner shape, the mean wind force coefficient of the rounded corner decreased the most regardless of side ratio.

Fig. 6 shows the variation of fluctuating torsional moment coefficient due to the side ratio for the corner chamfered shape. It can be clearly seen that when the side ratio increases, the fluctuating torsional moment coefficient also increases. In addition, for the corner chamfered shape, even if the corner modification rate changed, the C_T' did not change so clearly. In this figure, the calculated result of C_T' of a square prism is as given in AIJ-RLB. The experimental values were generally slightly smaller than those obtained from the AIJ-RLB's formula regardless of the corner modification rate and the side ratio, so it seems that the formula is appropriate.



(a) Corner modification rate b^*=0.05 (b) Corner modification rate b^*=0.2

Figure 5 Changes of mean drag force coefficient with side ratio

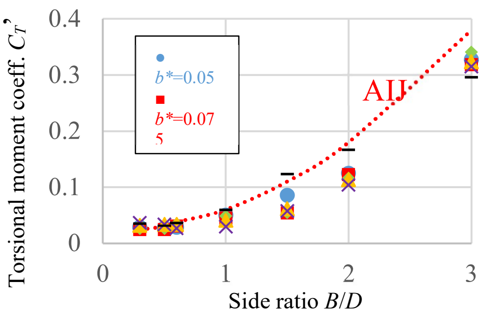


Figure 6. Changes of fluctuating torsional moment coefficient with side ratio (Corner chamfered models)

5. CONCLUSIONS

The wind force characteristics of high-rise buildings with various corner shapes and side ratios were investigated based on wind tunnel experiments. By changing the corner shapes, it was found that the wind force coefficients were lower than those of the prism. In addition, by changing the side ratio, the effect on the wind load when the corner shape was changed became smaller.

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